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Advanced Test Reactor Capabilities and Future Irradiation Plans

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ADVANCED TEST REACTOR CAPABILITIES AND FUTURE IRRADIATION PLANS

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1. Introduction

The Advanced Test Reactor (ATR), located at the Idaho National Laboratory (INL), is one of the most versatile operating research reactors in the Untied States. The ATR has a long history of supporting reactor fuel and material research for the US government and other test sponsors. The INL is owned by the US Department of Energy (DOE) and currently operated by Battelle Energy Alliance (BEA). The ATR is the third generation of test reactors built at the Test Reactor Area, now named the Reactor Technology Complex (RTC), whose mission is to study the effects of intense neutron and gamma radiation on reactor materials and fuels. The current experiments in the ATR are for a variety of customers – US DOE, foreign governments and private researchers, and commercial companies that need neutrons. The ATR has several unique features that enable the reactor to perform diverse simultaneous tests for multiple test sponsors. The ATR has been operating since 1967, and is expected to continue operating for several more decades. The remainder of this paper discusses the ATR design features, testing options, previous experiment programs, future plans for the ATR capabilities and experiments, and some introduction to the INL and DOE's expectations for nuclear research in the future.

2. ATR Description and Testing Capabilities

The ATR is a pressurized, light water-moderated, beryllium –reflected reactor; it operates at nominally 2.5 Mpa (360 psig) and 71°C (160°F). The unique capability of the ATR to provide either constant or variable neutron flux during a reactor operating cycle makes irradiations in this reactor very desirable. The maximum operating power is 250 MW, however, the reactor is currently operated closer to 110 MW, due to test sponsor requirements; the ATR is still capable of full power operations. Currently, operating cycles are 6-8 weeks in duration, with a 1 or 2 week outage, and annual availability is approximately 70%. The ATR core is comprised of 40 curved plate fuel elements, each containing 19 curved aluminum-clad uranium plates, arranged in a serpentine arrangement, around a 3 x 3 array of primary testing locations, called flux traps. These locations are the highest flux locations in the core. The physical configuration of the ATR, the 4-leaf clover shape, allows the reactor to be operated at different power levels in the four corner "lobes" to allow for different testing conditions for multiple simultaneous experiments. Figure 1 shows a cross section of the ATR core, with the irradiation locations identified. Currently, the US DOE is the primary user of the ATR, but there is increasing use by other US government programs, commercial organizations, and international researchers. The ATR was designed to accommodate a wide variety of testing requirements. The key design features are as follows:

- Large test volumes – 1.2 m long (at all testing locations) and up to 13 cm diameter
- A total of 77 testing positions
- High neutron flux – up to 1E15 n/cm^2-s thermal, up to 5E14 n/cm^2-s fas
- Variety of fast/thermal flux ratios (0.1 – 1.0)
- Constant axial power profile – rotating control drums instead of vertical control rods
- Power tilt capability- different power levels for experiments in same operating cycle
- Individual experiment control
- Simultaneous experiments in different test conditions
- Frequent experiment changes
- Core internals replacement every 10 years - all core internal equipment is replaced
- Solid stainless steel reactor vessel positioned ~ 1.2 m from the active core region to minimize vessel embrittlement – no current lifetime limit or shutdown date
- Accelerated testing for fuel development and materials testing

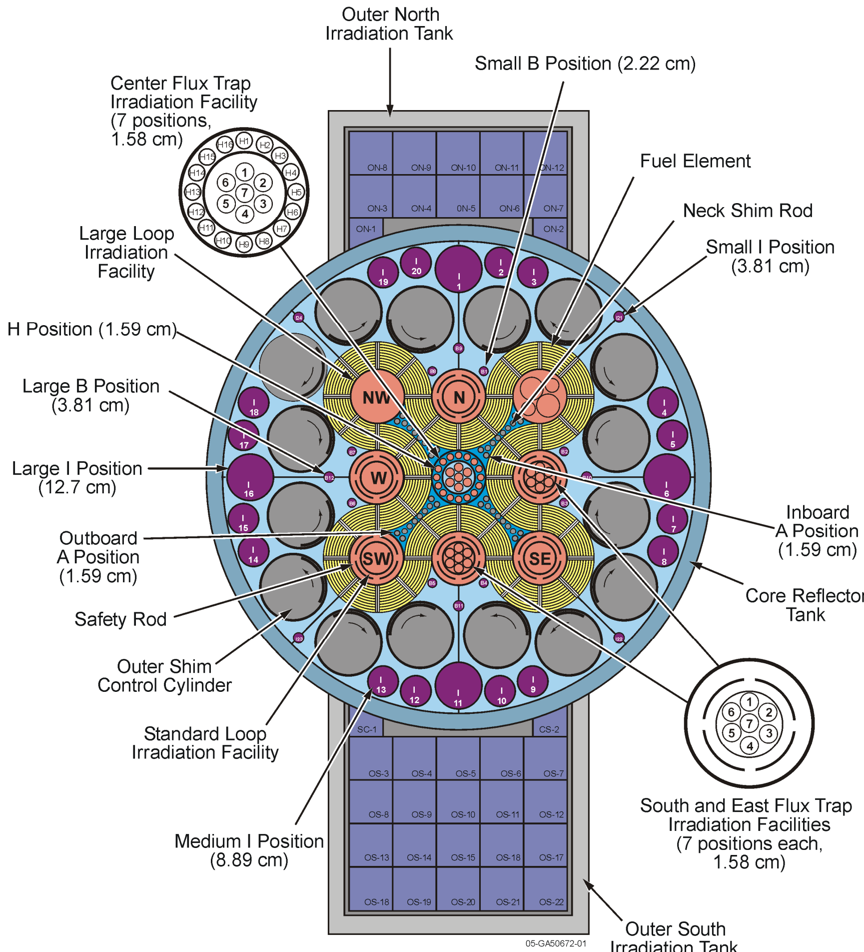

Figure 1 Core Map of the ATR

As testing has progressed at the ATR since initial operations, several changes to the reactor and plant have been made. One change to the reactor to expand the testing capabilities include addition of the Powered Axial Locator Mechanism (PALM), which allows experiments to be moved axially in and out of the reactor core flux region to simulate reactor startup and other transient conditions. The instrument and control reactor protection systems have been upgraded to more reliable systems, resulting in fewer unintentional RPS shutdowns. The number of unplanned scrams decreased from 11 in 1980 to 1 in 2004.

There are three basic types of experiment configurations utilized in the ATR – the static capsule, the instrumented lead, and the pressurized water loop experiment. Each is described in more detail below, with some examples of the experiments performed using each type of configuration.

2.1 Static capsule experiment

The simplest experiment performed in the ATR is a static capsule experiment. The material to be irradiated is sealed in aluminum, zircaloy, or stainless steel tubing. The sealed tube is placed in a holder that sits in a chosen test position in the ATR. A single capsule can be the full 1.2 m core height, or may be shorter, such that a series of stacked capsules may comprise a single test. Capsules are usually placed in an irradiation basket to facilitate the handling of the experiment in the reactor. Figure 2 shows a simplified drawing of the Mixed Oxide ("MOX") irradiation test capsule and basket assembly. Some capsule experiments contain material that can be in contact with the ATR primary coolant, and that need the cooling function; these capsules will not be sealed, but in an open configuration, such that the capsule is exposed to and cooled by the ATR primary coolant system. Examples of this are fuel plate testing, such that the fuel to be tested is in a cladding material similar to (or compatible with) the ATR fuel element cladding.

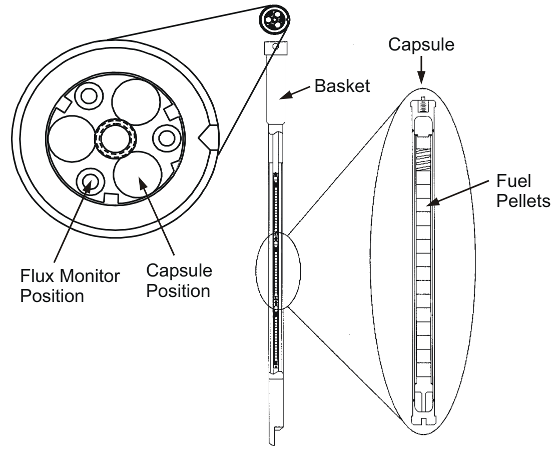

Figure2 Static Capsule Assembly for the MOX Experiment

Static capsules typically have no instrumentation, but can include flux-monitor wires and temperature melt wires for examination following the irradiation. Limited temperature control can be designed into the capsule through the use of an insulating gas gap between the test specimen and the outside capsule wall. The size of the gap is determined through analysis for the experiment temperature requirements, and an appropriate inert gas is sealed into the capsule.

Static capsule experiments are easier to insert, remove, and reposition than more complex experiment configurations. Relocations to a different irradiation location within the ATR are occasionally desired to compensate for fuel burn-up in a fuel experiment. A static capsule experiment is typically less costly than an instrumented one and requires less time for design and analysis prior to insertion into the ATR.

2.2 Instrumented lead experiment

The next level in complexity of ATR experiments is an instrumented lead experiment, which provides active monitoring and control of experiments parameters during the irradiation period. The primary difference between the static capsule and the instrumented lead experiment is an umbilical tube that runs from the experiment in the reactor through the reactor vessel and houses instrumentation connections that lead to a monitoring/control station elsewhere in the reactor building. In a temperature-controlled experiment, thermocouples continuously monitor the temperature in the experiment and provide feedback to a gas control system to provide the necessary gas cooling mixture to the experiments to achieve the desired experiment conditions. The thermocouple leads and the gas tubing are in the umbilical tube. A conducting (helium) gas and an insulating (typically neon or possibly argon) gas are mixed to control the thermal conductance across a predetermined gas gap. The computer-controlled gas blending system allows for the gas mixture to be up to 98% of one gas and as low as 2% of the other gas to allow for a wide range of experiment temperature ranges. Figure 3 shows a typical instrumented lead experiment.

Another feature of the instrumented lead experiment is the ability to monitor the gas around the test specimen for changes to the experiment conditions. In a fueled experiment, for example, there is sometimes a desire to test for fission gases, which could indicate a failure of the experiment specimen. Gas chromatography can also be used to monitor oxidation of an experiment specimen. The instrument leads allow for a real time display of the experiment parameters on an operator control panel. The instrumented leads can also be used to provide an alarm to the operators and experimenters if any of the experiment parameters exceed test limits. For any monitored experiment parameter, a data acquisition and archive capability can be provided. Typically the data are saved for six months on a circular first-in, first-out format.

The primary advantage to the instrumented lead experiment is the active control of the experiment parameters that is not possible in a static capsule experiment. Additionally, the experiment sponsor does not have to wait until the full irradiation has been completed for all experiment results; the instrumentation provides preliminary results of the experiment and specimen condition.

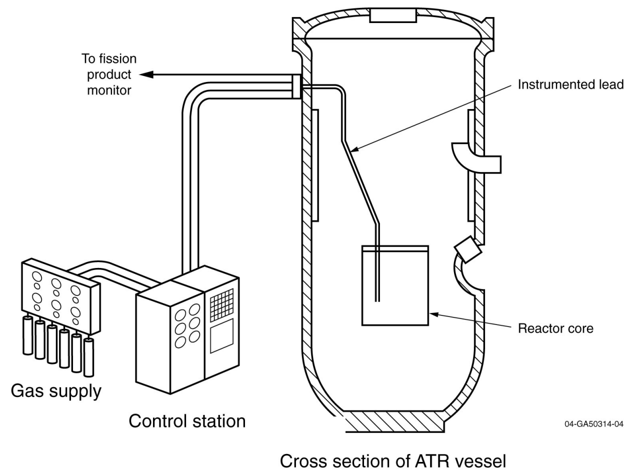

Figure 3 Example of an Instrumented Lead Experiment Configuration

2.1 Pressurized water loop experiment

The pressurized water loop (PWL) experiment is the most complex and comprehensive type of testing performed in the ATR. Five of the ATR flux traps contain in-pile tubes (IPTs), connected to pressurized water loops, that provide a barrier between the reactor primary coolant system and a secondary pressurized water loop coolant system. The experiments are isolated from the ATR reactor coolant system since the IPT extends through the entire reactor vessel. There are closure plugs at the top and bottom of the vessel to allow the experiments to be independently inserted and removed.

The secondary cooling system includes pumps, coolers, ion exchangers, heaters to control experiment temperature, and chemistry control systems. As in the instrumented lead experiments, all of the secondary loop parameters are continuously monitored, and computer controlled to ensure precise testing conditions. Loop tests can precisely represent conditions in a commercial pressurized water reactor. Operator control display stations for each loop continuously display information that is monitored by the reactor operations staff. Test sponsors receive preliminary irradiation data before the irradiations are completed, so there are opportunities to modify testing conditions if needed. The data from the experiment instruments are collected and archived similar to the data in the instrumented lead experiments. The real-time feedback of experiment conditions and irradiation results can also be an asset to the experiment sponsor.

3. Previous and Current Irradiation Testing in the ATR

The tests performed in the ATR have been diverse in their design, objectives, and sponsors. The ATR has been used to support major nuclear reactor research initiatives for the United States and international collaborations. Some of the more notable experiments are discussed here.

As part of the nuclear non-proliferation initiatives, it was proposed that weapons grade plutonium could be mixed with commercial uranium oxide and burned in current light water reactors (LWR). In order to qualify the fuel for use in commercial LWRs, some tests were performed in the ATR on the MOX fuel. A simple capsule was prepared to contain nine fuel samples; the samples were exposed to a variety of burnups to simulate LWR burnup profiles. Data suggest that MOX would be an acceptable fuel form for LWRs.

In the late 1980's, the US was interested in designing and deploying smaller high temperature reactors – Modular High Temperature Gas Reactor (MHTGR). Several tests for particle fuels were planned in the ATR. One experiment was performed, but the project was cancelled, so these tests were also discontinued. The data obtained from this experiment, however, have been valuable in establishing fuel fabrication techniques and fuel testing program for the Advanced Gas Reactor project as part of the Very High Temperature Reactor development.

As part of ageing studies for a commercial nuclear power company, several stainless steel samples were irradiated to simulate power plant neutron damage. Experiment objectives were to determine particle migration, and to perform stress corrosion cracking studies of the irradiated samples. One experiment required some additional flux enhancement, so additional fuel was included as part of the experiment in the test location to ensure that the flux received by the experiment was appropriate for the test data needs.

The Advanced Fuel Cycle Initiative (AFCI) is currently performing tests in the ATR. Currently all the tests are in simple capsules, to burn various compositions of metal and nitride fuels. The overall AFCI irradiation testing objective is to determine what fuel materials could reduce the amount of minor actinides in current LWR to minimize the need for long-term storage of spent fuel waste.

As part of the Global Threat Reduction Initiative, high-enriched uranium fuel is discouraged in all research and test reactors. The Reduced Enrichment for Research and Test Reactors (RERTR) program was initiated to develop and qualify new fuels to enable conversion of the reactor fuels to low enriched uranium. ATR has been used as the primary testing location for the new fuel types and will continue to be used until all reactor fuel development is completed and new fuels are fabricated. These tests have been and will be static capsule configurations in reflector and flux trap positions.

In support of life extension studies for the Magnox reactors, graphite samples were irradiated to high-density losses due to radiolytic oxidation in a gas controlled, high temperature environment in a temperature controlled instrumented experiment. Some samples were irradiated in an inert environment, and others were in a CO_2 environment to assess the environmental effect on the density loss. The experiment successfully achieved the results the customer wanted, however, final analysis results are still pending.

The ATR has been used in the past for production of radioisotopes. Currently, the only isotope in regular production is cobalt-60, although there is interest from several private companies in initiating production of other radioisotopes.

4. Future Irradiation Tests Planned or Proposed in the ATR

Several of the current irradiation programs will continue in the ATR for a few years, or indefinitely – AFCI, RERTR, Co-60. Additional tests are planned for various sponsors.

Several organizations are interested in performing boiling water reactor (BWR) simulations in the ATR. These tests will require modification of a PWL to simulate the BWR conditions (i.e., voids in the core region), as well as modifications to the current safety basis and operating processes of the ATR, and have the potential to yield valuable information about BWR aging issues, and design constraints on new BWRs.

The Advanced Gas Reactor (AGR) program is currently planning several tests to be performed on particle fuels in the ATR for the next ten years. These tests will be instrumented lead experiments, and will utilize active temperature control.

The Next Generation Nuclear Plant (NGNP) is planning to perform graphite creep experiments. The nuclear grade graphites used in currently operating reactors are no longer available, however, the currently available graphites have not undergone as much testing as is necessary to use them in new reactor designs. The US DOE has started design of an experiment to collect creep data.

The US government is interested in long duration, deep space missions that will require long-lived power sources, such as the Pu-238 powered radioisotope power system (RPS). The DOE is currently considering moving the RPS processes to the INL, in part because of the suitability of the ATR to produce the Pu-238.

5. Future Activities for the ATR

The DOE and BEA have committed to a strong future for the ATR. The fifth core internals replacement was completed in January 2005, so that the reactor structural internals, fuel, and in-reactor testing facilities are all new. The next core internals replacement is tentatively scheduled for 2013, with a full testing schedule up until the outage. Additionally, some modifications have been proposed and work has begun, to keep the ATR available to a variety of customers for several more decades, if there are testing needs.

The current contractor operating the ATR, BEA, has committed to DOE to implement several upgrades to the ATR capabilities. The total financial commitment for the upgrades is $20M in the next eight years. These upgrades are:

- Remanufacture and reinstallation of the Irradiation Test Vehicle (removed in 2004), which is a multi-capsule (up to 15 simultaneous tests) high-temperature testing system, previously installed in the center flux trap. Each test can have an independent control system.
- Reactivation of a pressurized water test loop and installation of an additional In-Pile-Tube. This loop would support commercial nuclear power plant test programs for both pressurized water reactors (PWR) and BWRs for high burnup fuel development and plant reliability research.
- Determination of the hot cell needs to complement the reactor capabilities. Currently there are no operational hot cells at the RTC, however, there are hot cells and radio analytical laboratories nearby, at the Materials and Fuels Complex (MFC).
- Installation a new transfer shuttle irradiation system (i.e., a rabbit) that can be used for short-term tests or short half-lived isotope production. An additional area of research that could be performed at the INL with the rabbit system is neutron activation analysis.
- Upgrade of some of the ATR fuel fabrication equipment. In addition to the ATR fuel, this production facility also produces fuel for other research reactors, and conversion of research reactor fuel to low enriched uranium (LEU) will require modifications to the fuel fabrication facility.

As part of the RERTR program, the ATR fuel is expected to be converted from high enriched uranium to low enriched uranium. There is still substantial analysis and fuel development needed to ensure that ATR testing capabilities are not diminished after the conversion.

6. Conclusion

The ATR continues Idaho's tradition of pioneering nuclear reactor research, and will continue well into the 21st century as an important contributor to DOE's nuclear research objectives. Additionally, collaborative and complementary capabilities of other research reactors will be vital to achieve the objectives of several national and international initiatives. DOE's commitment to the INL and BEA's commitment to invest in the ATR upgrades will ensure that the ATR is ready and available to meet nuclear research needs for many diverse experiment sponsors for many years to come.

7. Acknowledgements

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8. References

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